Software GPS Receiver

and

Applications

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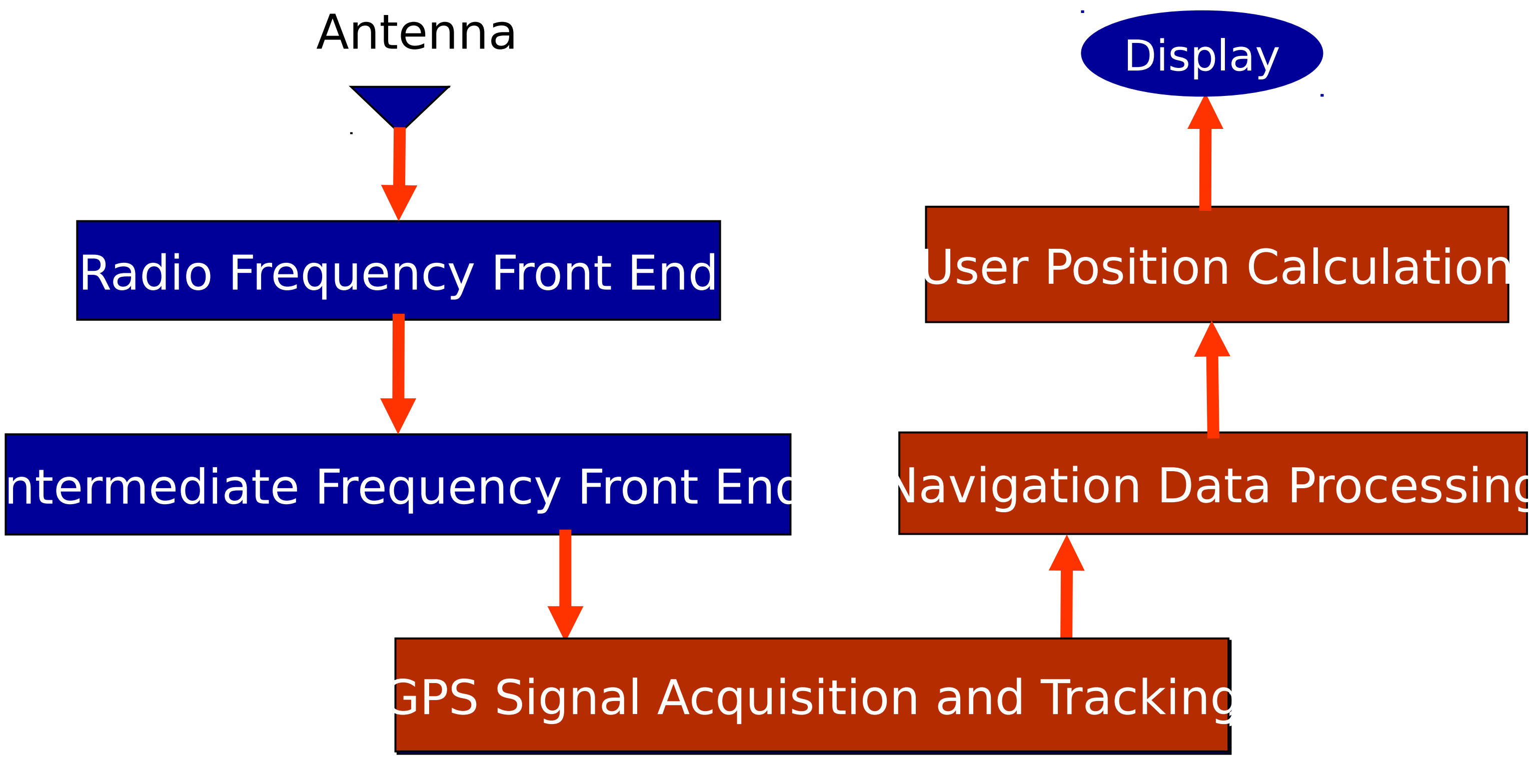
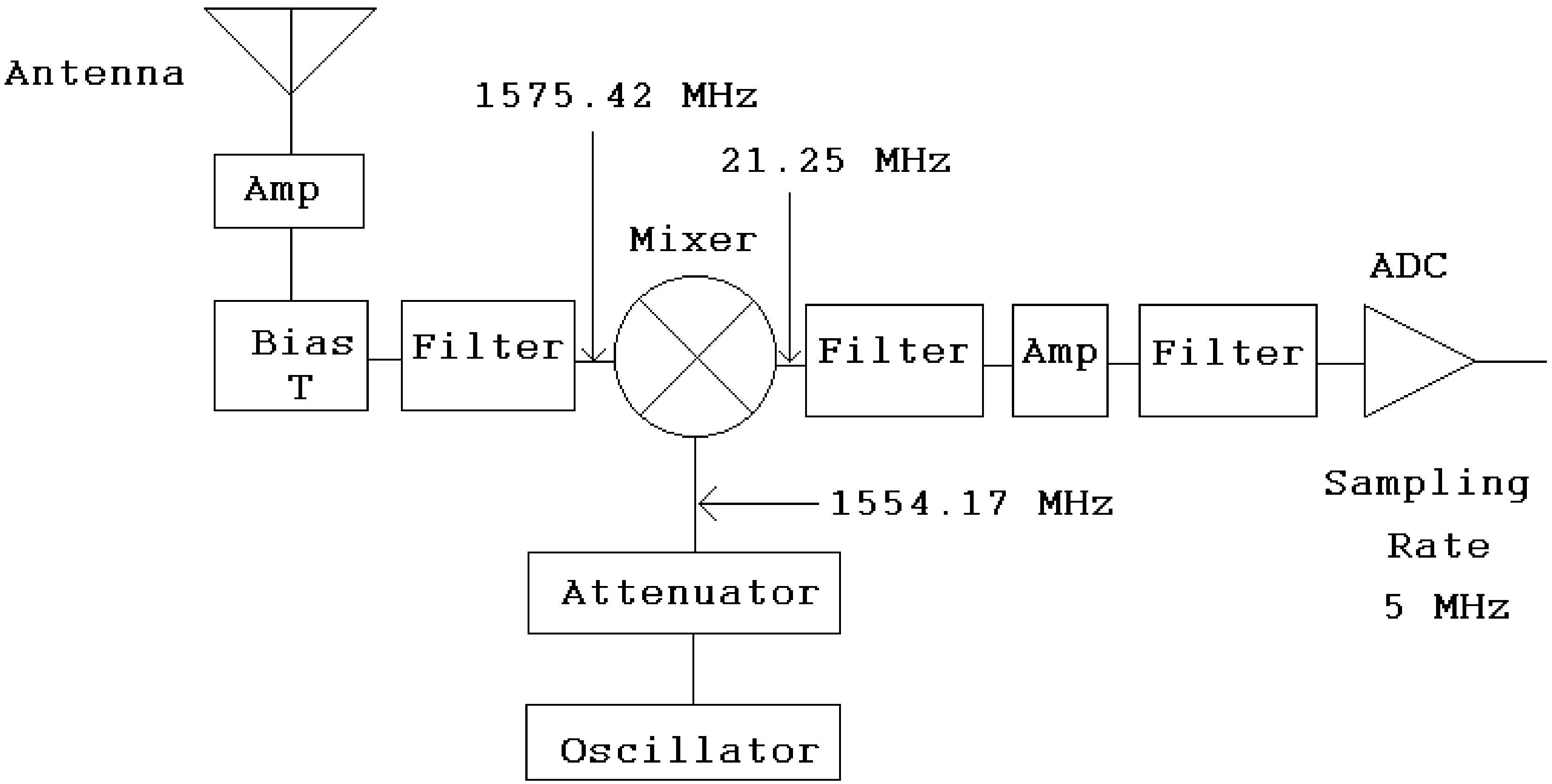
Presentation Outline

- **Software GPS Receivers**
- **Application Problems**
  - **Navigation in Urban Environment**
  - **UWB-GPS Interference Study**
  - **Related Projects**
- **Conclusions**

Software GPS Receiver



A GPS Receiver Front End



Input GPS Signal

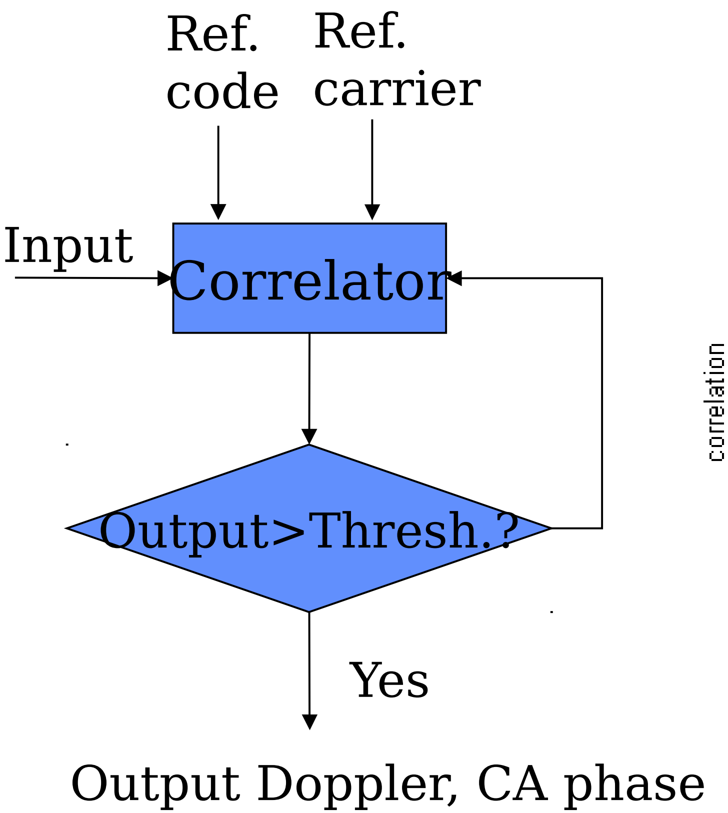
$$x(t) = \sum_i a_i D_i(t) CA_i(t, t_i^0) \sin(2\pi f_i + \varphi_i) + n + w$$

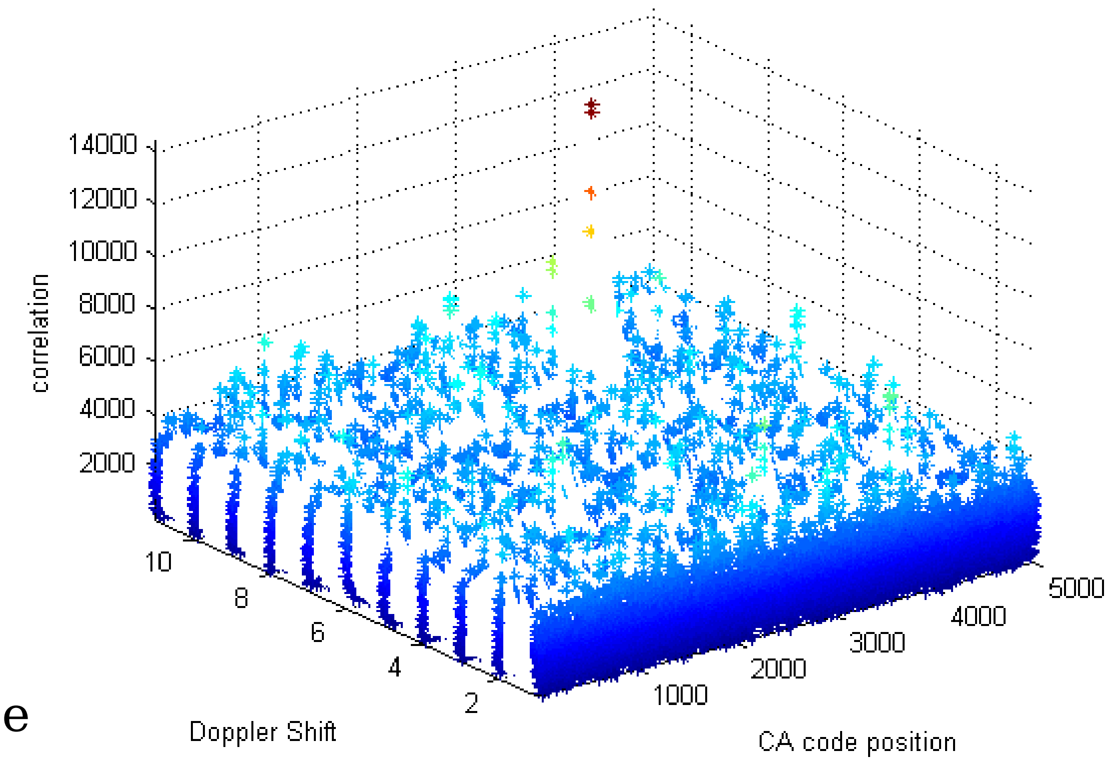
i: satellite number
a_i: carrier amplitude
D_i: Satellite navigation data bits (data rate 50 Hz)
CA_i: C/A code (chipping rate 1.023 MHz)
t: time
t_i^0: C/A code initial phase
f_i: carrier frequency
φ_i: carrier phase
n: noise

GPS Signal Acquisition

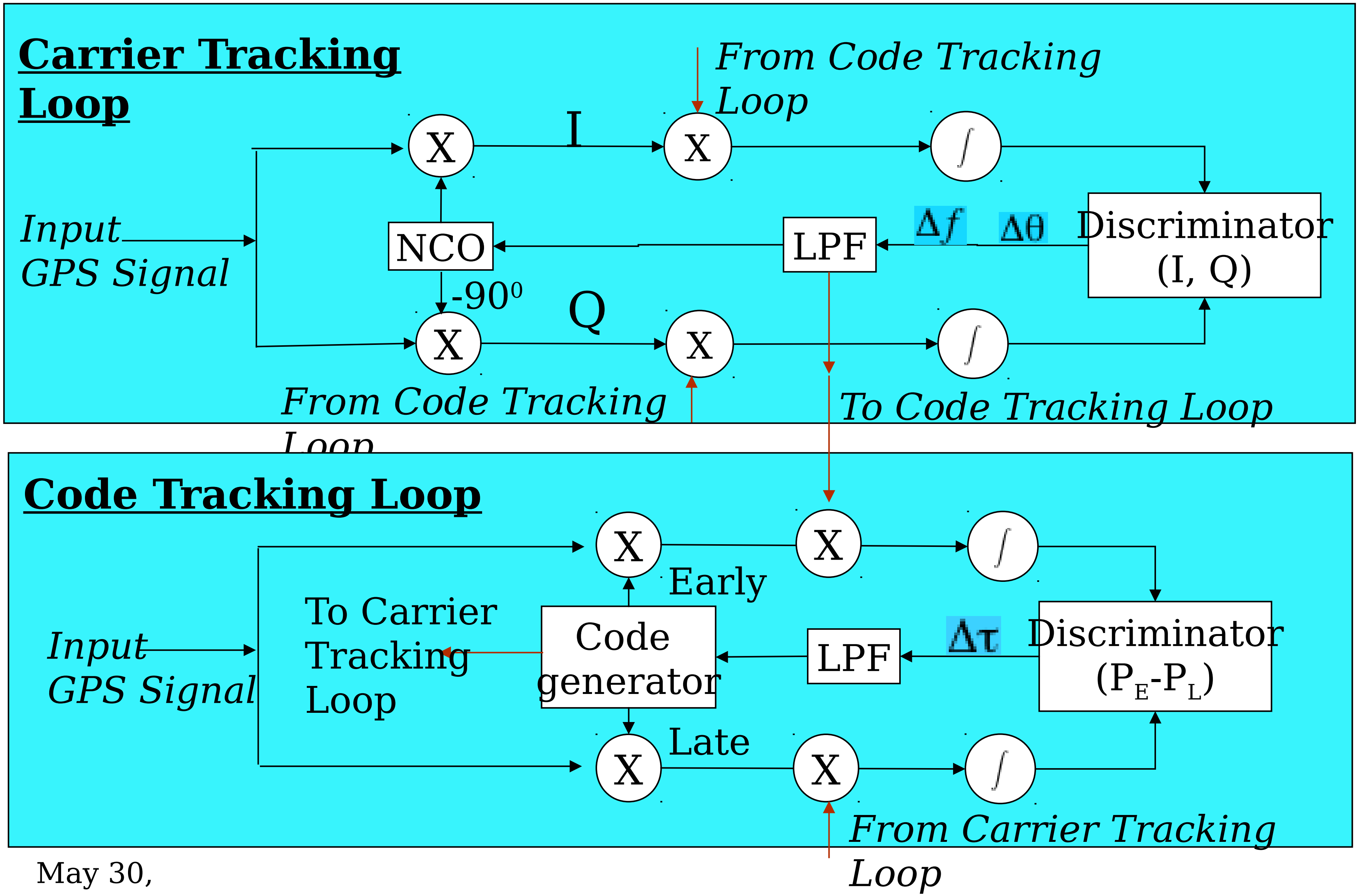
Goal: Coarse estimates of (1) carrier Doppler frequency

(2) CA code phase



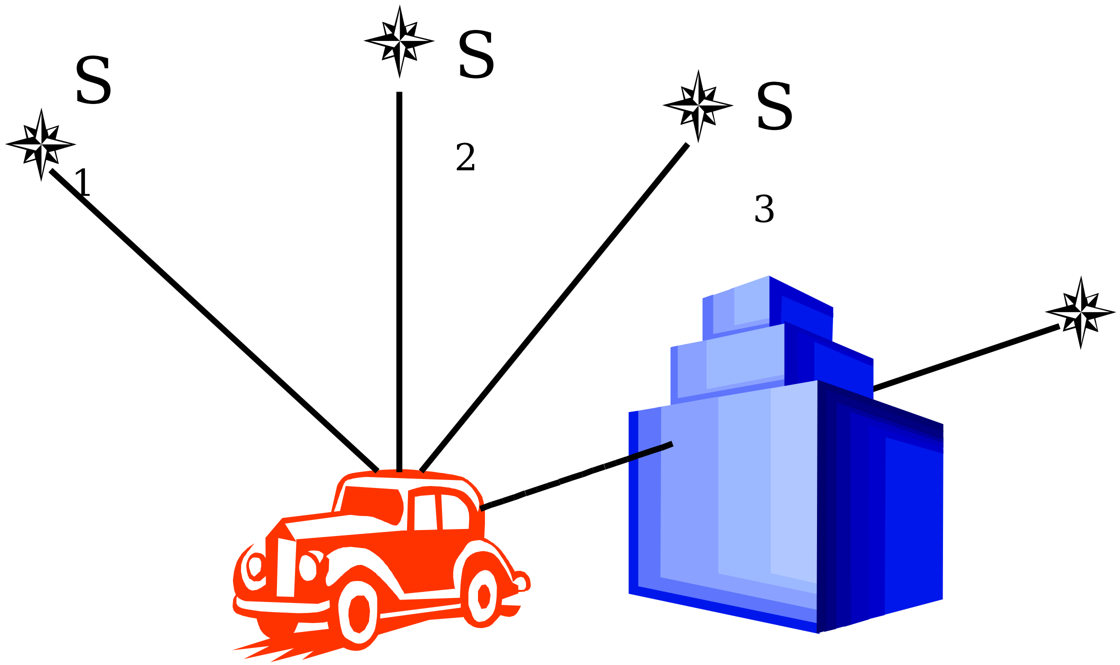


GPS Signal Tracking



Application Problems

Navigation In Urban Environment



1. Self-interference between strong and weak sig

2. Weak signal processing

Cross-correlation Power Analysis

Cross-correlation: $CA_w \otimes s$ $\qquad s = \sqrt{P_s}\, CA_s$

Cross-correlation power: $N_c = E[(CA_w \otimes s)^2]$

$$= P_s E[(CA_w \otimes CA_s)^2]$$

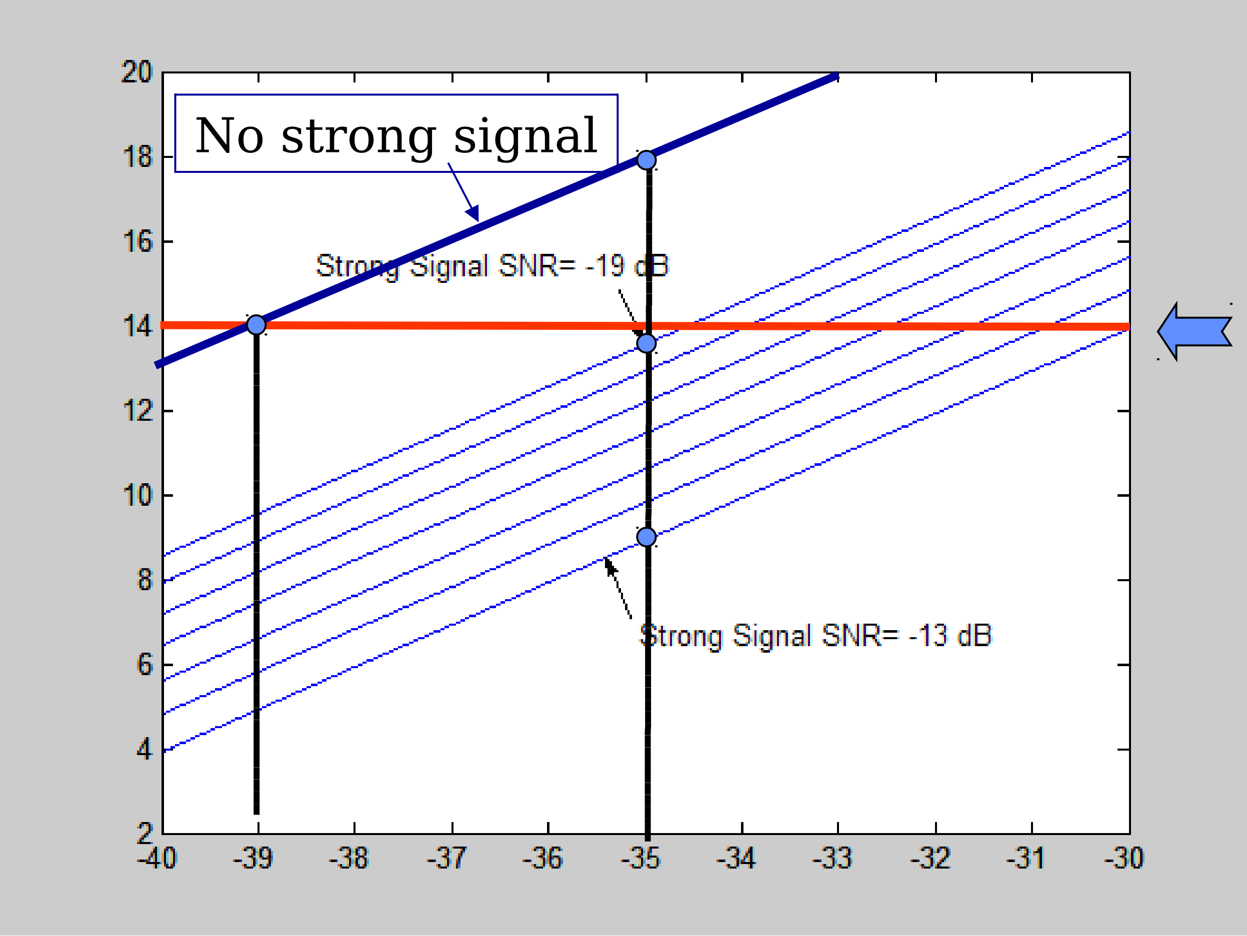
Let: $C = E[(CA_s \otimes CA_w)^2]$

Processed weak signal: $SNR'_w = 10 \log \dfrac{P_w}{N_c + N/G}$

$$\boxed{SNR'_w = SNR_w + G_{dB} - 10 \log(CG\, 10^{\frac{SNR_s}{10}} + 1)}$$

Processed Weak Signal SNR

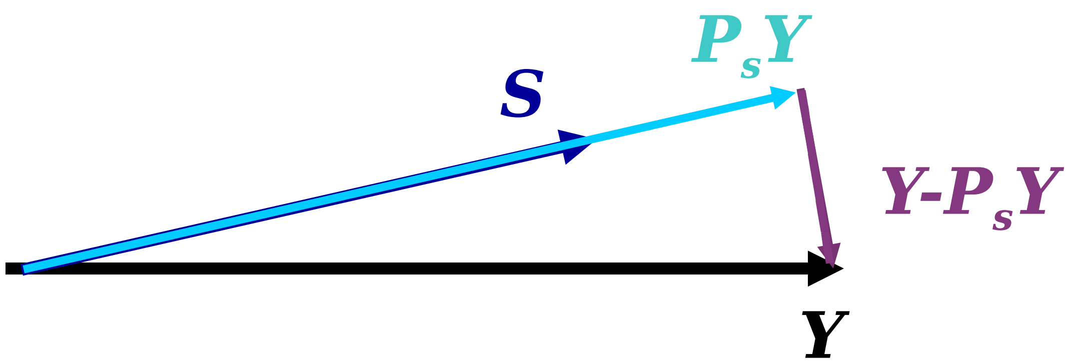
SNR'_w



Detector performance criteria

SNR_w

Projection Method



Y: Total received signal

S: Acquired strong signal space

P

P_sY: Projected received signal on to acquired signal space

$Y\text{-}P_sY$: Noise + weak satellite signals + errors

Projection Method Continued

$$P_s Y = S(S^T S)^{-1} S^T Y$$

$$\mathbf{S} = [S_1, S_2, \ldots, S_i, \ldots]$$

$$S_i = \begin{bmatrix} CA_i(0)\sin(\varphi_i) \\ CA_i(t_s)\sin(\omega_i t_s + \varphi_i) \\ CA_i(2t_s)\sin(2\omega_i t_s + \varphi_i) \\ \vdots \\ CA_i(nt_s)\sin(n\omega_i t_s + \varphi_i) \end{bmatrix}$$

$$t_s = 1/f_s$$

$$Y = a_w H + a_s S + n$$

Weak Strong Noise

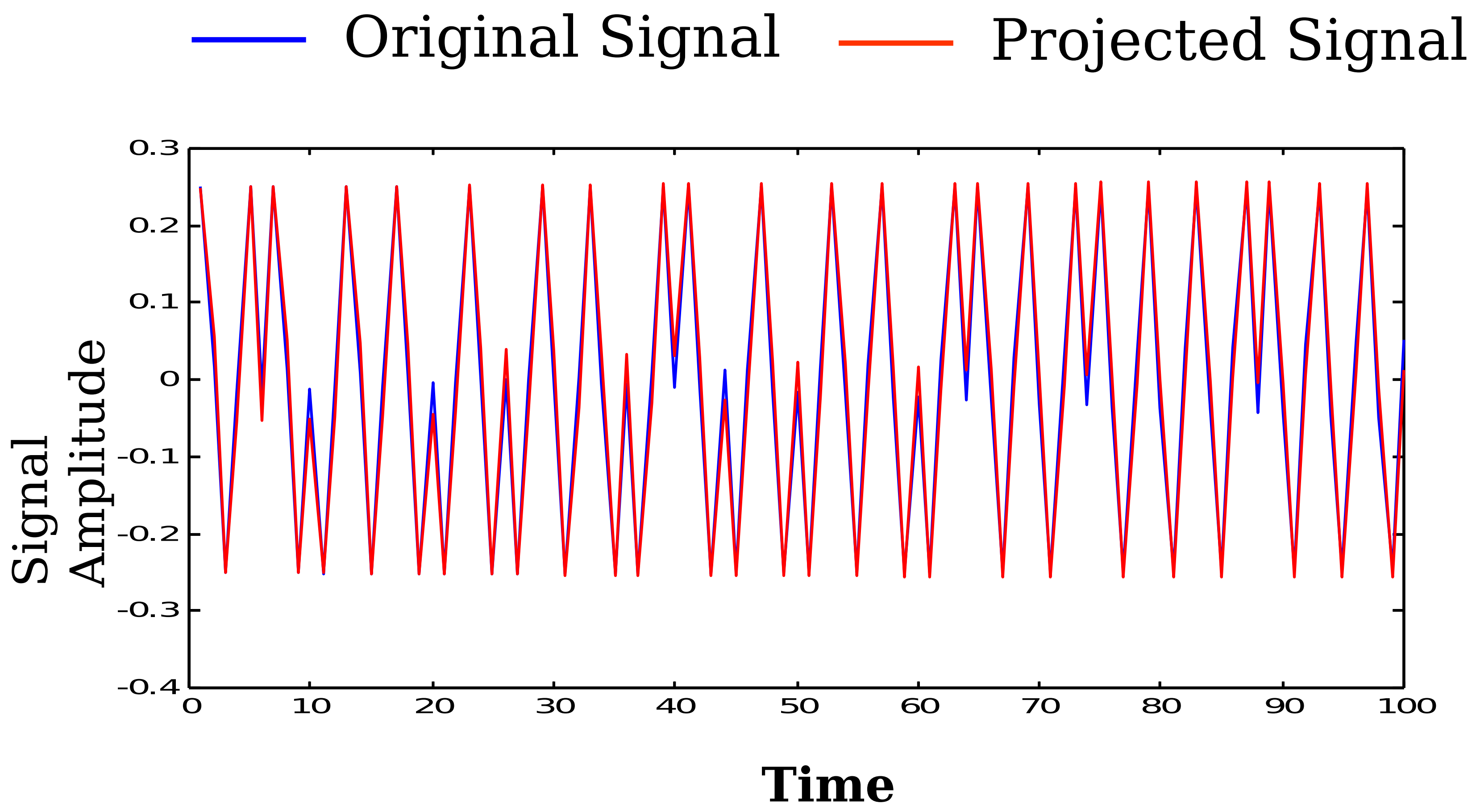
$$P_s Y = S(S^T S)^{-1} S^T (a_w H + a_s S + n)$$

$$S^T . H \cong 0 \quad a_w << a_s$$

$$P_s Y \cong a_s S + P_s n$$

$$Y - P_s Y \cong a_w H + n$$

Example


Original Signal
Projected Signal
Signal Amplitude
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
0
10
20
30
40
50
60
70
80
90
100
Time

Weak Signal Acquisition

Goal: **C/N_0=24 dB-Hz**
(BW=2MHz, **SNR=-39 dB**

Detector limit:
SNR=14 dB

Need 53 dB process gain

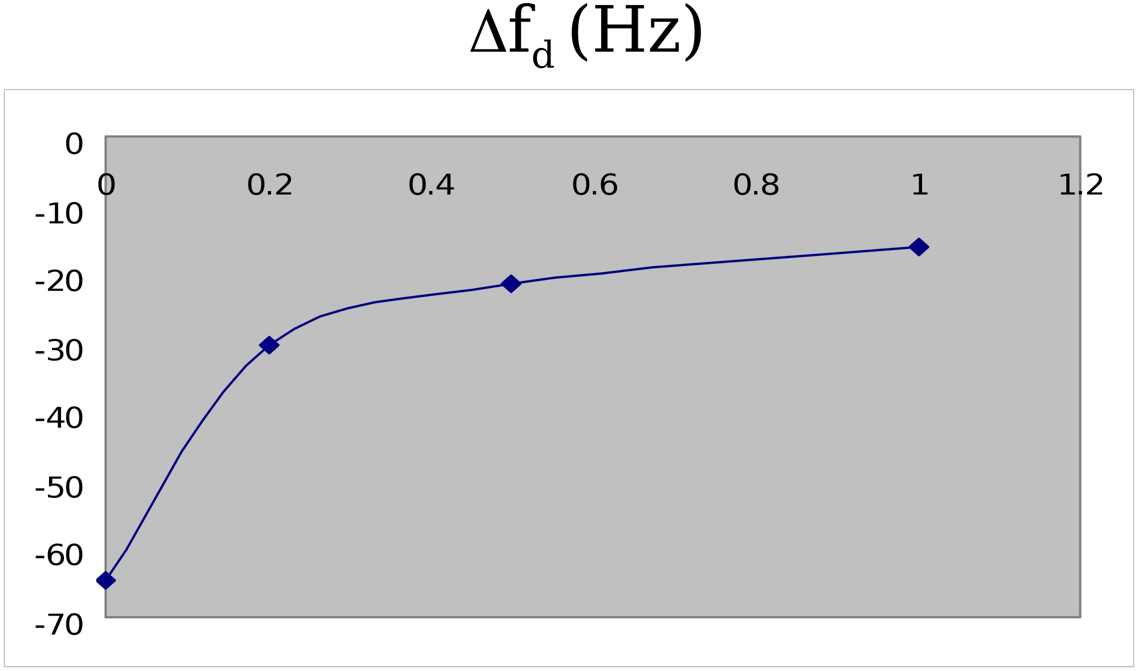
Coherent integration

+

Incoherent integration

Coherent Integration Length Limit

- **Navigation data transition**
  - **Occurs once 20 ms**
  - **Limit to 10 ms coherent integration lengt**
- **Strong signal cancellation residue**



Incoherent Integration Gain Needed

10 ms coherent integration

↓

BW: 2MHz → 100 Hz
G = 43 dB

↓

Need 10 dB gain
Incoherent integration

Incoherent Integration Gain Calculation

$$G_i = 10\log(m) - L(m)$$

$$L(m) = 10\log\left(\frac{1+\sqrt{1+9.2m/D_c(1)}}{1+\sqrt{1+9.2/D_c(1)}}\right) dB$$

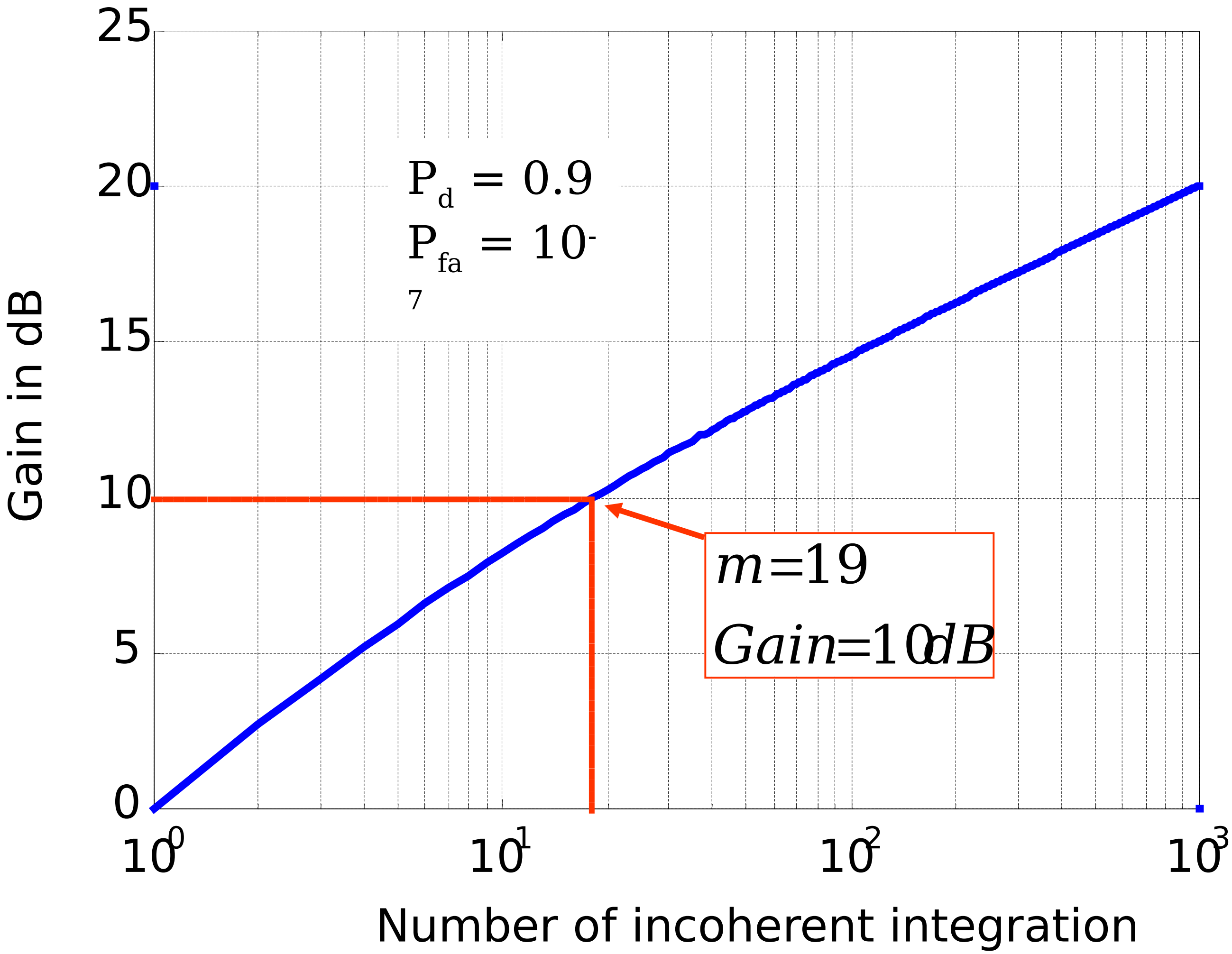
$$D_c(1) = [erfc^{-1}(2P_{fa}) - erfc^{-1}(2P_d)]^2$$

m: Number of incoherent integration

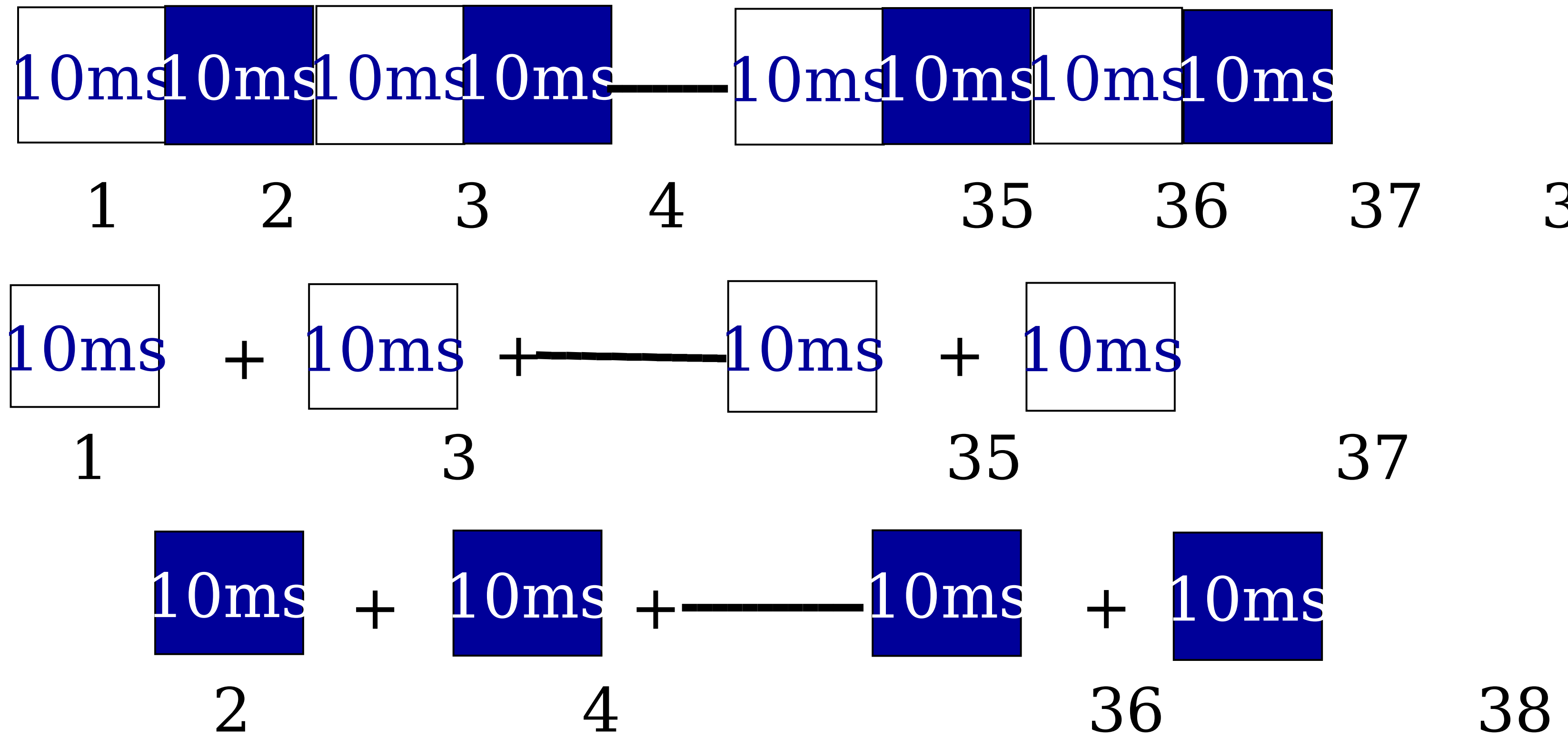
P_{fa}: Probability of false alarm

P_d: Probability of detection

Incoherent Integration Gain

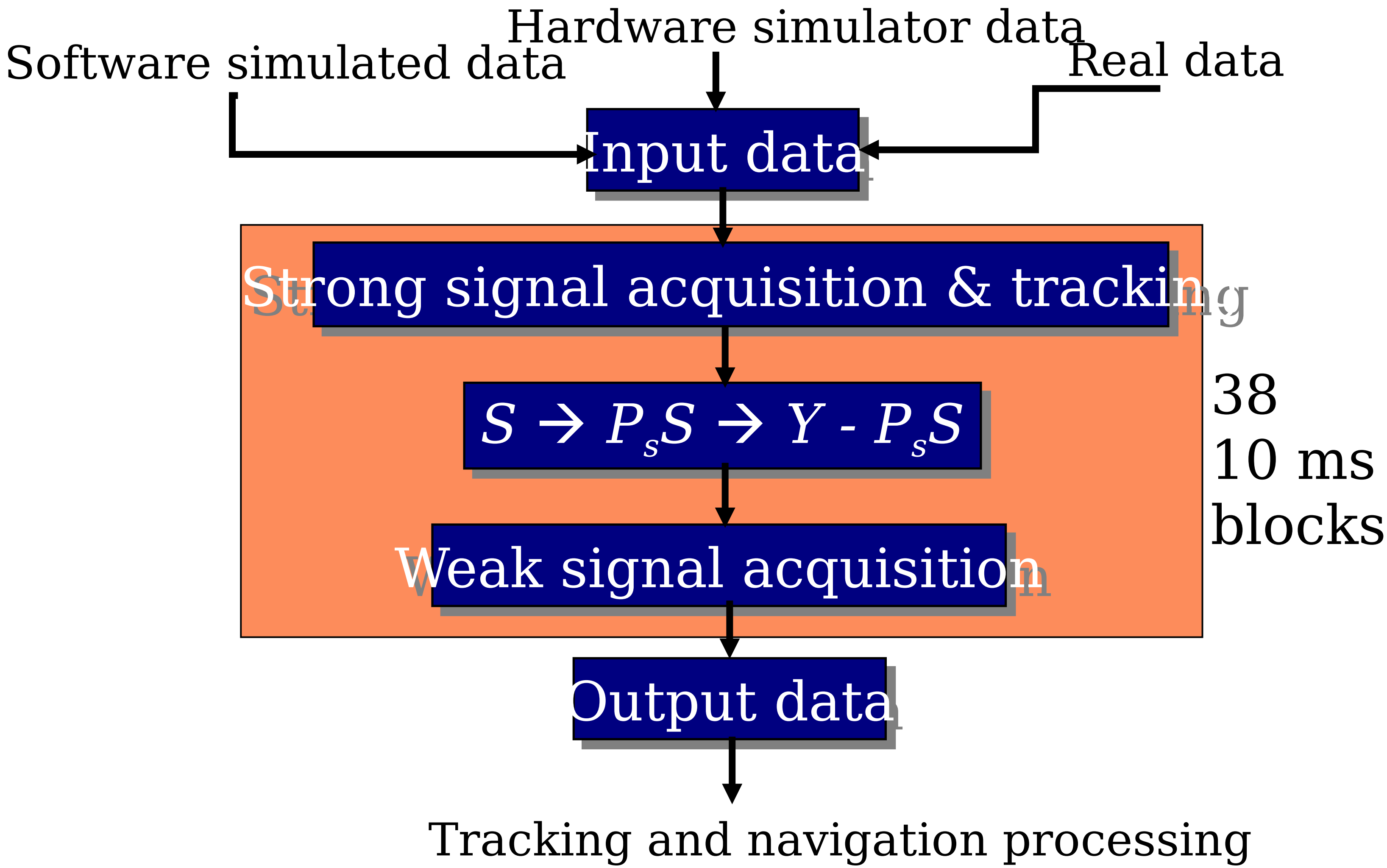


An Example Approach for Weak Signal Acquisition



10 ms coherent integration (43 dB) + 19 Incoherent Integration (10 dB) → Total gain (53 dB)

Processing Block Diagram



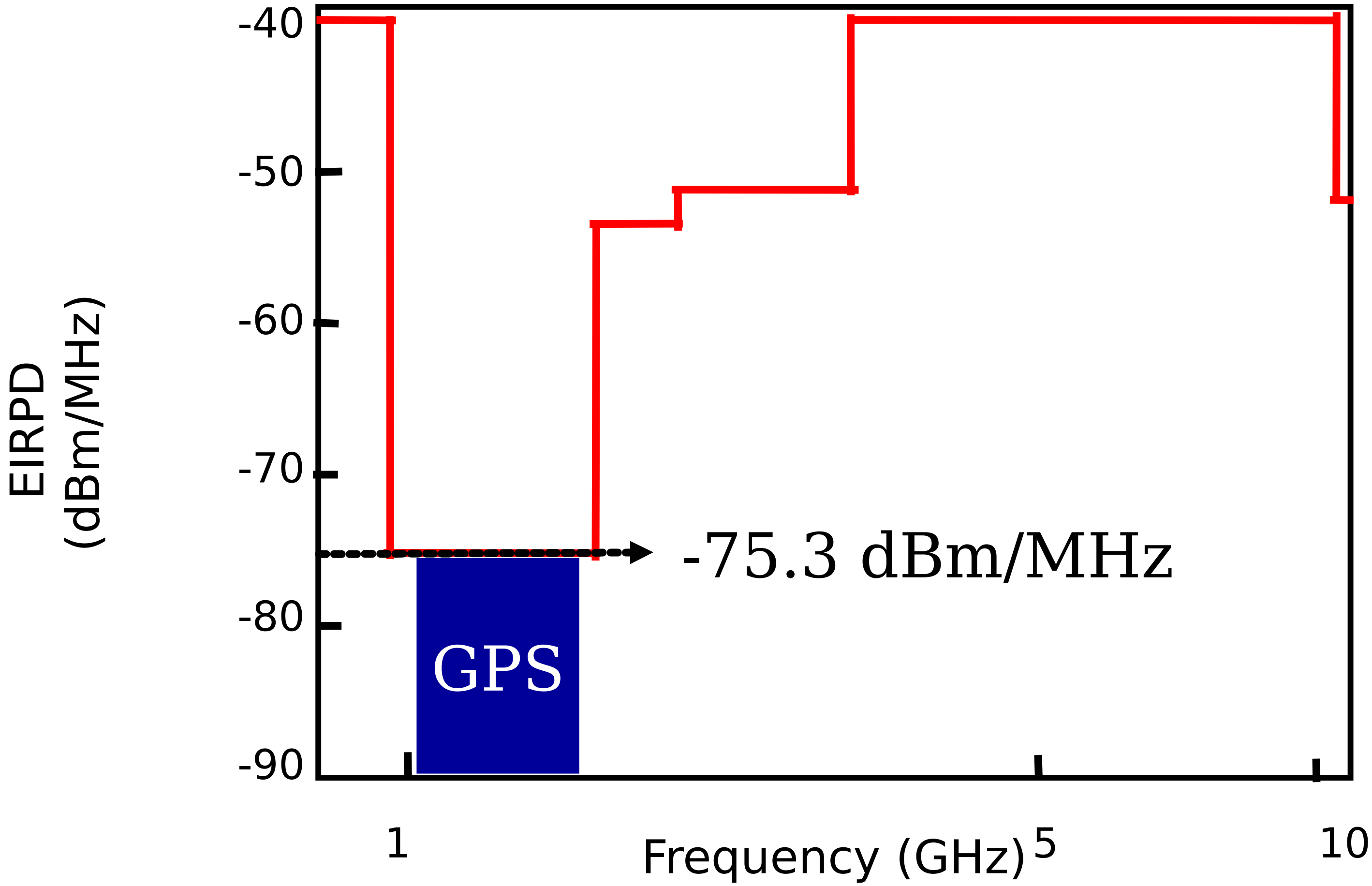
Test Results

- No strong signal present
  - **SNR=-40 dB (C/N_0=23 dB-Hz)** acquired
- Strong signal present, no cancellation

Lowest weak sig. SNR acquired	Strong signal SNR
-32 dB (C/N_0=31 dB-Hz)	**-13 dB (C/N_0=50 dB-Hz)**
-33 dB (C/N_0=30 dB-Hz)	**-15 dB (C/N_0=48 dB-Hz)**
-35 dB (C/N_0=28 dB-Hz)	**-17 dB (C/N_0=46 dB-Hz)**

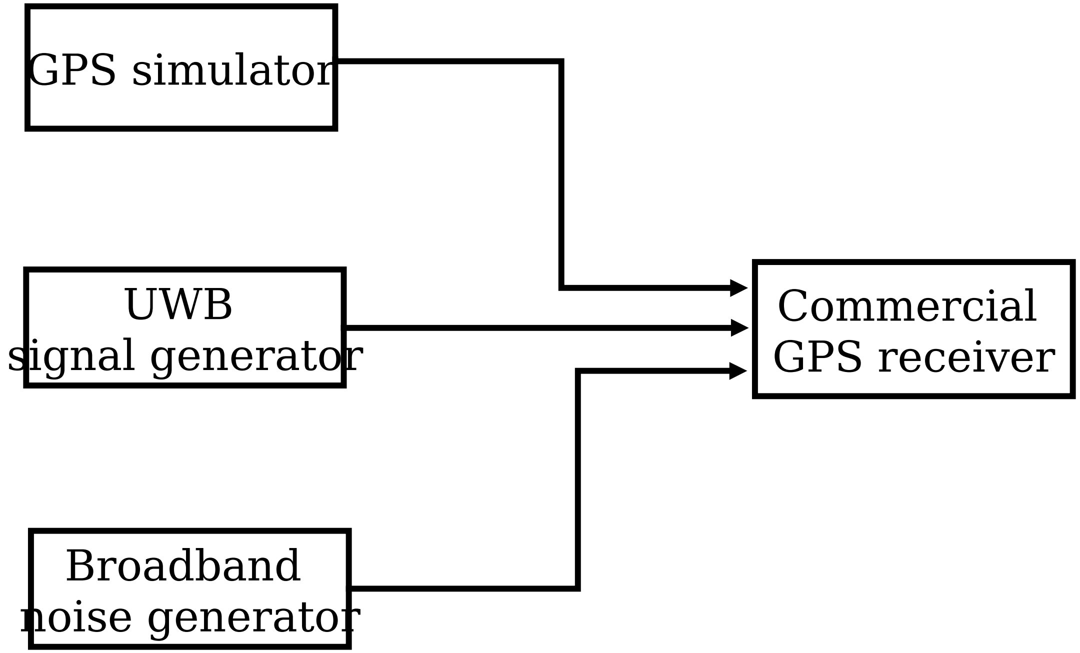
  - **SNR=-39 dB (C/N_0=24 dB-Hz)** acquired

UWB-GPS Interference Study

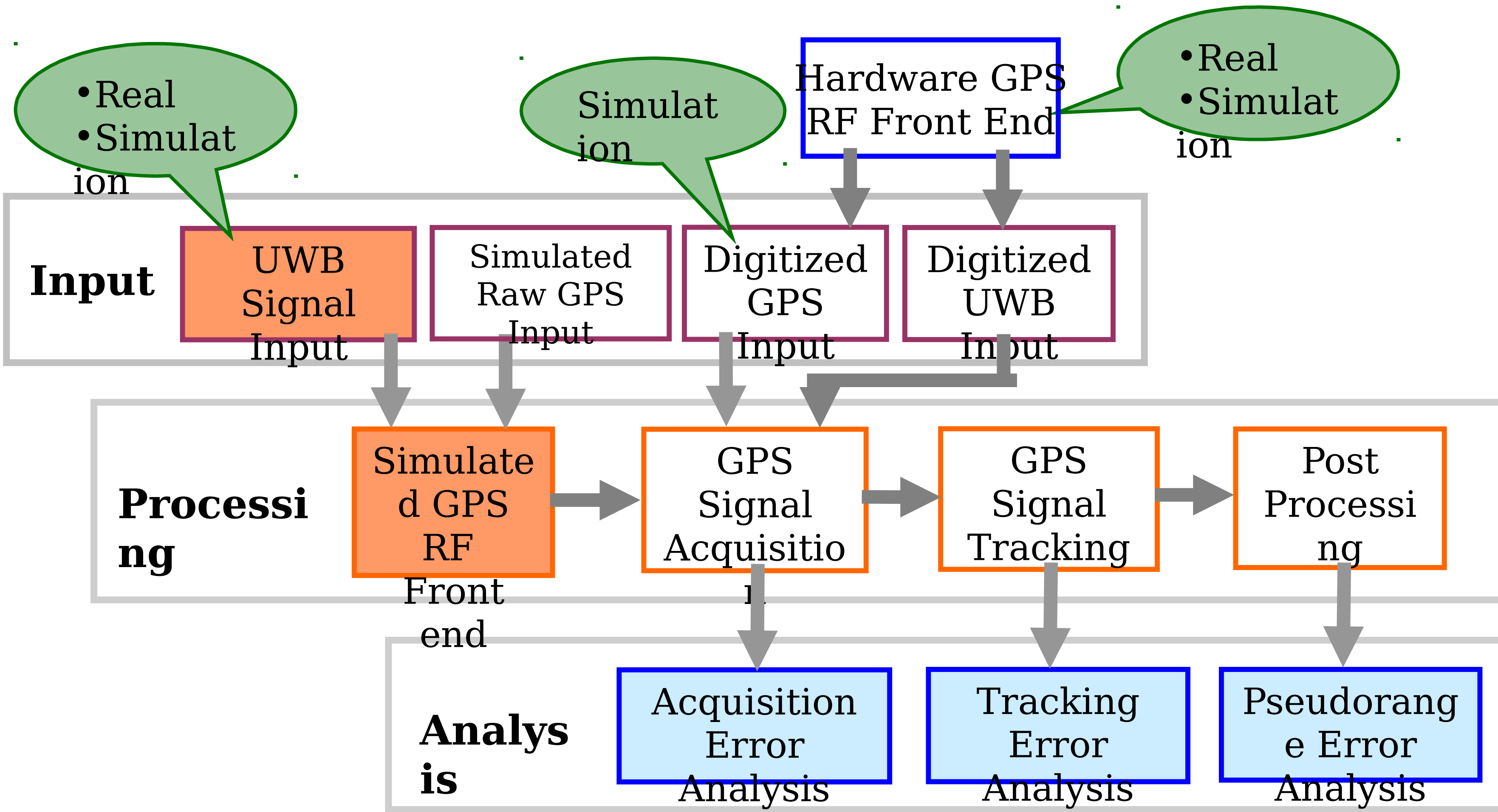


FCC Spectrum Mask (2002)

Previous UWB/GPS Interference Studies



New UWB/GPS Interference Studies Framework



GPS RF Front End Simulation Model

UWB input signal (simulated) f_{sIn}=20 GHz

UWB input signal (real samples) f_{sIn}=20 GHz

UWB Input

$x[n]$

GPS RF Front End

GPS Antenna System
$h_a(t) \Leftrightarrow H_a(\omega)$

y_1

Down Conversion
f_{L1} (1.57542 GHz) $\Rightarrow$ f_{IF} (21.25 MHz)

y_2

Narrow Band Band-pass Filter
$h_b(t) \Leftrightarrow H_b(\omega)$

y_3

Gain compensation

y_4

Sampling
f_{sOut}=5 MHz

y

To Acquisition

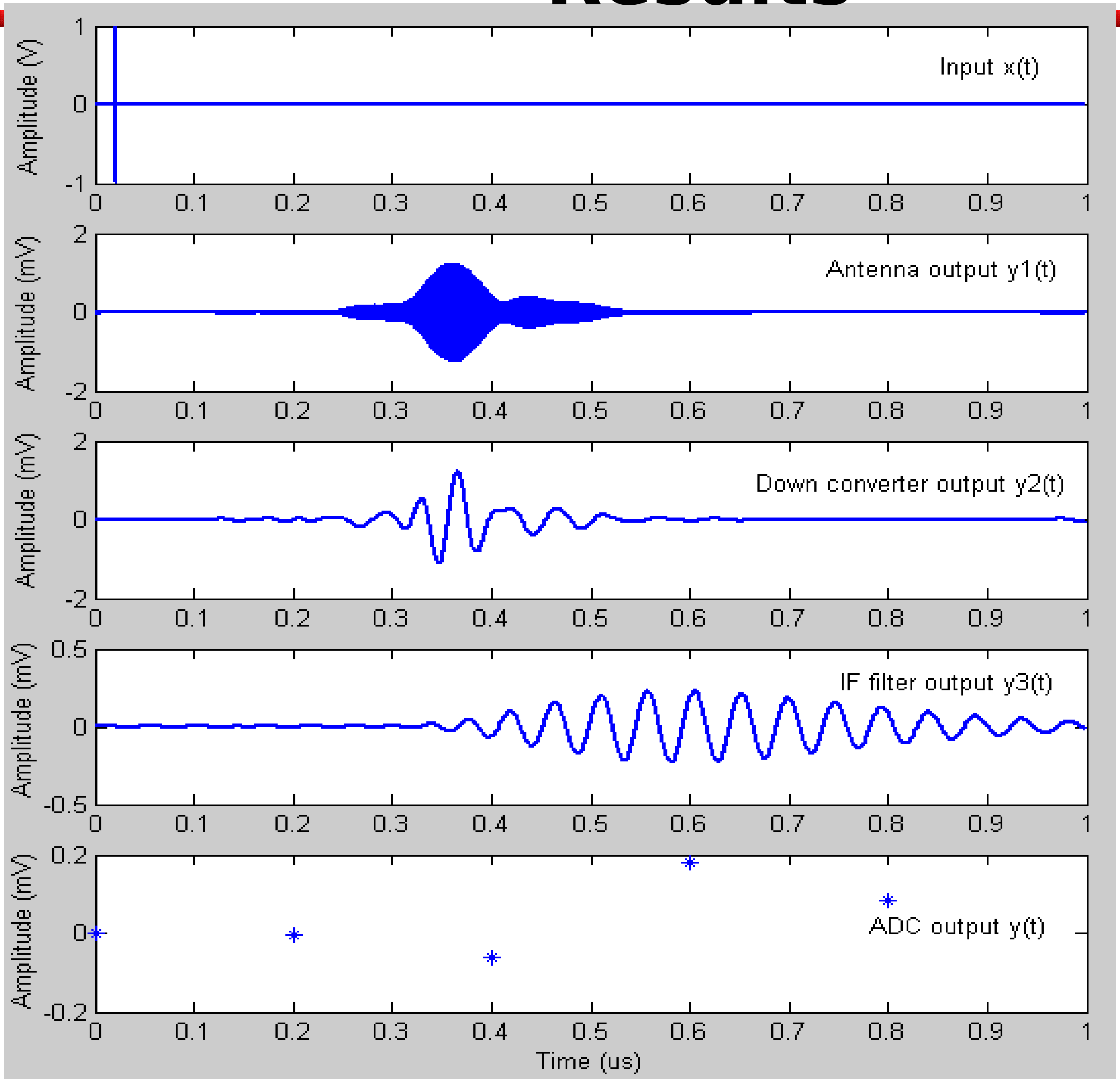
$y_1[n]=x[n]*h_a[n]$

$y_2[n]=y_1[n]\,exp(-j2\pi(f_{L1}-f_{IF})n/f_{sIn})$

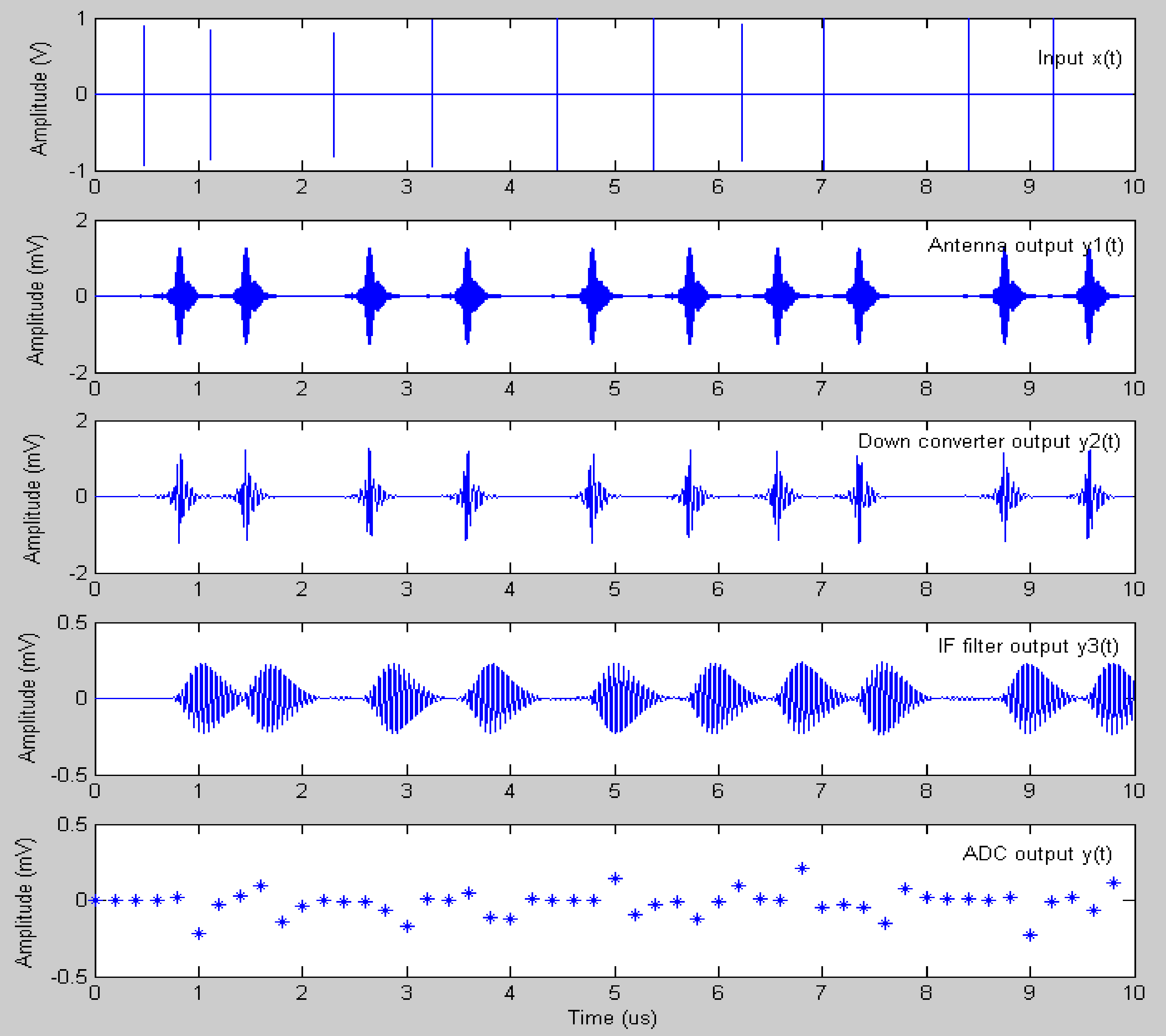
$y_3[n]=y_2[n]*h_b[n]$

$y[n]=y_3[n\, f_{sOut}/f_{sIn}]$

Preliminary Simulation Results



Preliminary Simulation Results

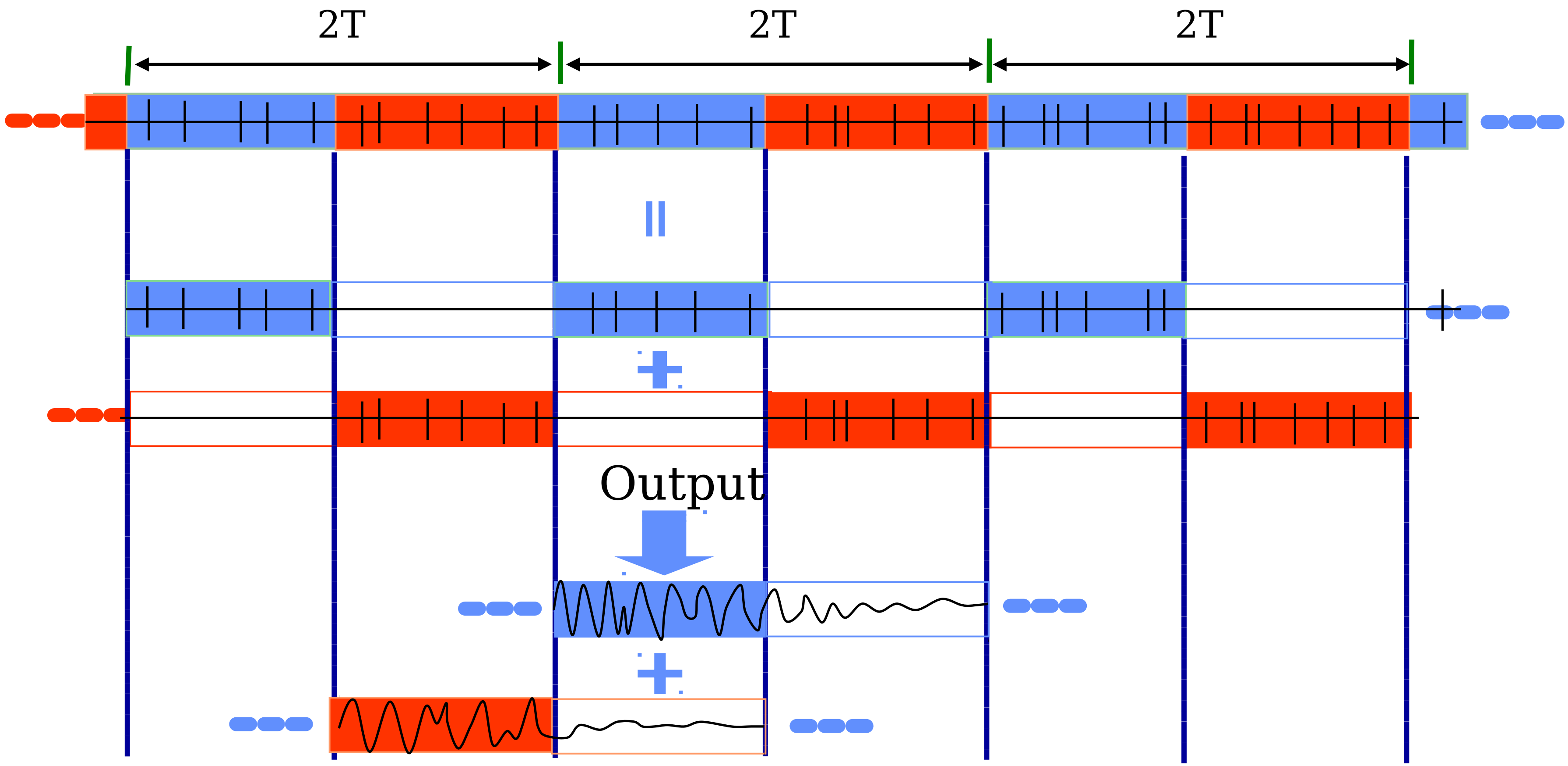


Large Signal Vector Size Handling

- **UWB signal vector size**
  - **f_s=20 GHz, 1 ms data → 2x10^7 samples**
  - **Weak signal acquisition →4x10^9 samples**
  - **Developed an algorithm to handle any data length**

Handling Large UWB Signal Samples

T: Time duration for a pulse output to remain significant



Large UWB Signal Samples Algorithm

Output =0

Input one block samples

Pad the next block with 0's

GPS RF Front End Simulation Model

Store the 1st block output as *temp1*
Store the 2nd block output

The 1st block *output*= *temp1+out*
Store the 2nd half block

Write *output* to file

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Software GPS Receiver Acquisition Success Rate

PRF (MHz)	Amp =0.1 V									
	1	5	10	25	55	110	160	200	320	420
Acq. Rate	98%	98%	98%	98%	97%	98%	97%	97%	93%	94%
EIRPD (DBm/MHz)	-98.6	-90.9	-87.8	-84.0	-80.5	-76.8	-75.1	-74.9	-72.5	-71.9

100 Transmitters
6 ft from GPS receiver

Software GPS Receiver Acquisition Success Rate

PRF (MHz)	Amp =0.2 V									
	1	**5**	**10**	**25**	**55**	**110**	**160**	**200**	**320**	**420**
Acq. Rate	**99%**	**98 %**	**97 %**	**97%**	**96%**	**92%**	**89 %**	**85%**	**82%**	**69%**
EIRPD (DBm/MHz)	**-92.6**	**-84.9**	**-81.8**	**-78.0**	**-74.5**	**-70.8**	**-69.1**	**-68.9**	**-66.5**	**-65.9**

100 Transmitters
6 ft from GPS receiver

Conclusions

- **Software receiver is an effective tool for research and handling of challenges**
- **Navigation in urban environment:**
  - **Block projection method can effectively caqncel CA code self-interference**
  - **Weak signal with C/N_0=24 dB-Hz can be acquired without aid and extensive computation power**
  - **Algorithms as problems when frequency cross-over occurs**
- **UWB-GPS interference studies**
  - **Software approach offers more flexibility as UWB signals and modulation schemes continuously evolve**
  - **Hybrid software front end model using simulation/real hardware features possible**
  - **Established a general software framework for UWB-GPS interference studies**

Other Related Projects

- High speed interface between RF frond end and processor development
- Integrated physiological and location monitoring and processing system
- Integrated navigation and control for autonomous vehicle
- Digital beam forming techniques

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Thank you

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